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TECHNICAL NOTE

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A SCINTILLATION COUNTER TELESCOPE FOR CHARGE AND MASS IDENTIFICATION OF PRIMARY COSMIC RAYS

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SUMMARY

Two major objectives of the experiment employing the scintillation counter telescope described here are the determination of: (1) the amount of interstellar material through which primary cosmic rays pass between their source and the earth's vicinity; and (2) the rigidity dependence of the modulation mechanism of hydrogen and helium nuclei. The telescope is a combination of scintillators (CsI crystals) giving both the energy E of the charged particle and its rate of energy loss dE/dx. The method is sensitive to particles whose energy is sufficient to penetrate the dE/dx scintillator, yet too low to pass through the E one. In satellite applications, both the dE/dx and E signals will be analyzed and sorted digitally into 256 channels. Two ranges of sensitivity will be required to detect heavy particles as well as protons and alpha particles. Data from a series of cosmic ray balloon flights made with a prototype of this detector are presented.

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INTRODUCTION

A cosmic ray telescope has been developed to study the charge and energy spectra of primary cosmic radiation. The two major objectives of this program are:

(1) To determine the amount of interstellar material through which primary cosmic rays have passed between their source and the vicinity of the earth (this amount can be deduced from the shape of the low-energy spectra of the primary nuclei, from helium to oxygen, measured at solar minimum); and

(2) To study the rigidity dependence of the various forms of H and He nuclei modulations.

A secondary objective is to study the charge and energy spectra of cosmic rays produced by the sun.

The telescope described herein is a combination of scintillators giving both the energy of a charged particle and its rate of energy loss dE/dx. This technique has been used extensively in medium-energy nuclear physics and in the study of the charge spectra of light fission fragments. A prototype detector was flown in balloons for a series of cosmic ray measurements in July 1961. Excellent charge and energy resolutions were obtained for electrons, protons and alpha particles late in the large cosmic ray event of July 1961. It is planned to fly a satellite version of the instrument on the first NASA Orbiting Geophysical Observatory. This report covers both the data obtained from balloon flights and the proposed satellite instrumentation.

COSMIC RAY MEASUREMENTS AT THE PREVIOUS SOLAR MINIMUM

During the last period of solar minimum, the charge and energy spectra of primary cosmic radiation were measured at balloon altitudes by the Cerenkov detector-scintillation counter technique (Reference 1). The experiment yielded the energy spectra of H and He nuclei for energies above

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150 Mev/nucleon, and the rigidity dependence of the various forms of cosmic ray modulations. Similar results were obtained for Be through O at energies above 450 Mev/nucleon, with a better charge resolution than is generally achieved in nuclear emulsion work. The results are interpreted as placing an upper limit of 4 gm/cm^2 on the amount of interstellar hydrogen traversed by the C, N and O nuclei.

During the coming period of solar minimum, it appears vital to extend these observations to the lower energies that are accessible by the dE/dx and E technique, in order to obtain greater sensitivity in the measurements of both the modulation mechanisms and the shapes of the energy spectra of heavy particles.

THE dE/dx AND E TECHNIQUE

Figure 1 shows the scintillator assembly. There are three scintillators; two measure energy loss, and one acts as a guard counter. A signal is received from both energy loss scintillators when a coincidence occurs, unless the guard scintillator shows that a particle has entered it as well. The top scintillator is made as thin as is consistent with a reasonable light output, so that a charged particle passing through it will be little changed in energy. The light output of this scintillator is then a measure of the particle's rate of energy loss. If the particle is stopped by the lower scintillator, the light output from this scintillator is a measure of the energy of the particle. If the particle completel traverses the E scintillator, an anticoincidence signal from the guard scintillator indicates that the particle has lost only part of its energy in the E scintillator, and the energy measurements are discarded. The particle's energy and its rate of energy loss, together with the theoretical relation between these quantities, identifies the particle. This detector is sensitive to those particles with enough energy to penetrate the dE/dx scintillator, yet little enough to be stopped in the E scintillator.

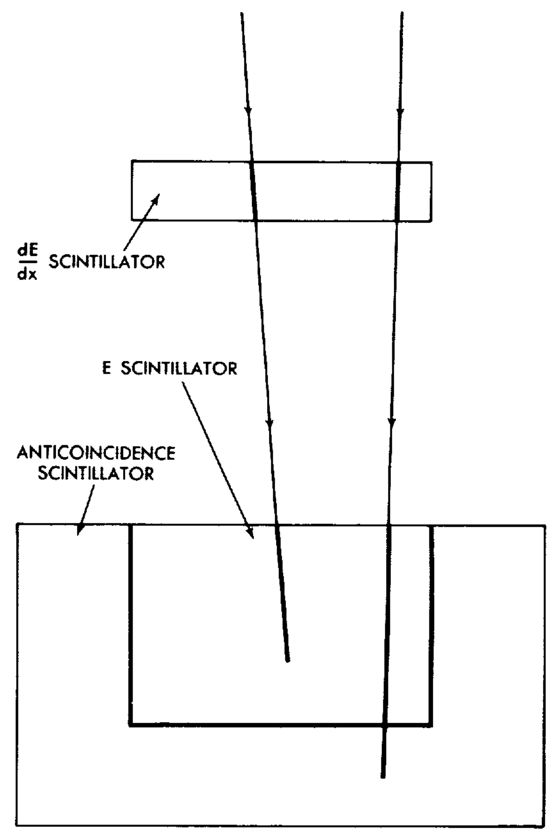


Figure 1—Schematic of scintillator assembly.

DETECTOR ASSEMBLY

A diagram of the detector is shown in Figure 2. The dE/dx scintillator, a CsI crystal 0.15 gm/cm^2 thick and 5 cm in diameter, is viewed by the upper left photomultiplier in the Figure. The E scintillator, a CsI crystal 10 gm/cm^2 thick and 5 cm in diameter, is viewed by the center photomultiplier. An aluminum alloy foil 0.001 gm/cm^2 thick optically divides the space between the scintillators. It is essential, of course, that the material in this space be kept to a minimum. The anticoincidence scintillator, a cup-shaped plastic scintillator surrounding the sides and bottom of the E scintillator, is viewed by a third photomultiplier shown at the right. A block diagram of the electronic assembly is shown in Figure 3.

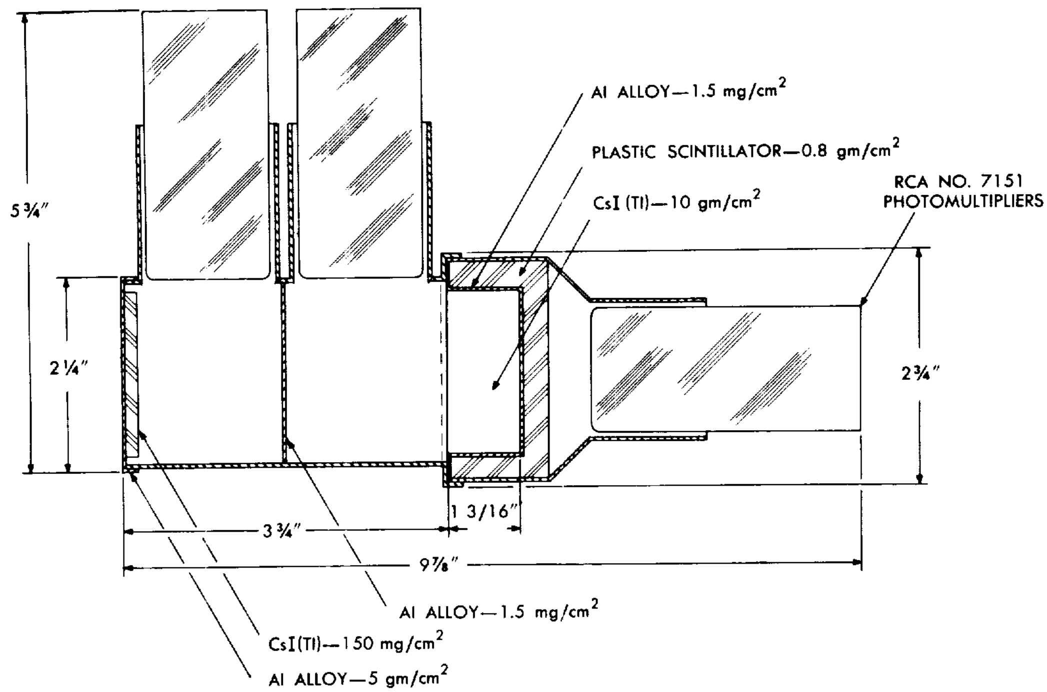


Figure 2—Detector Configuration.

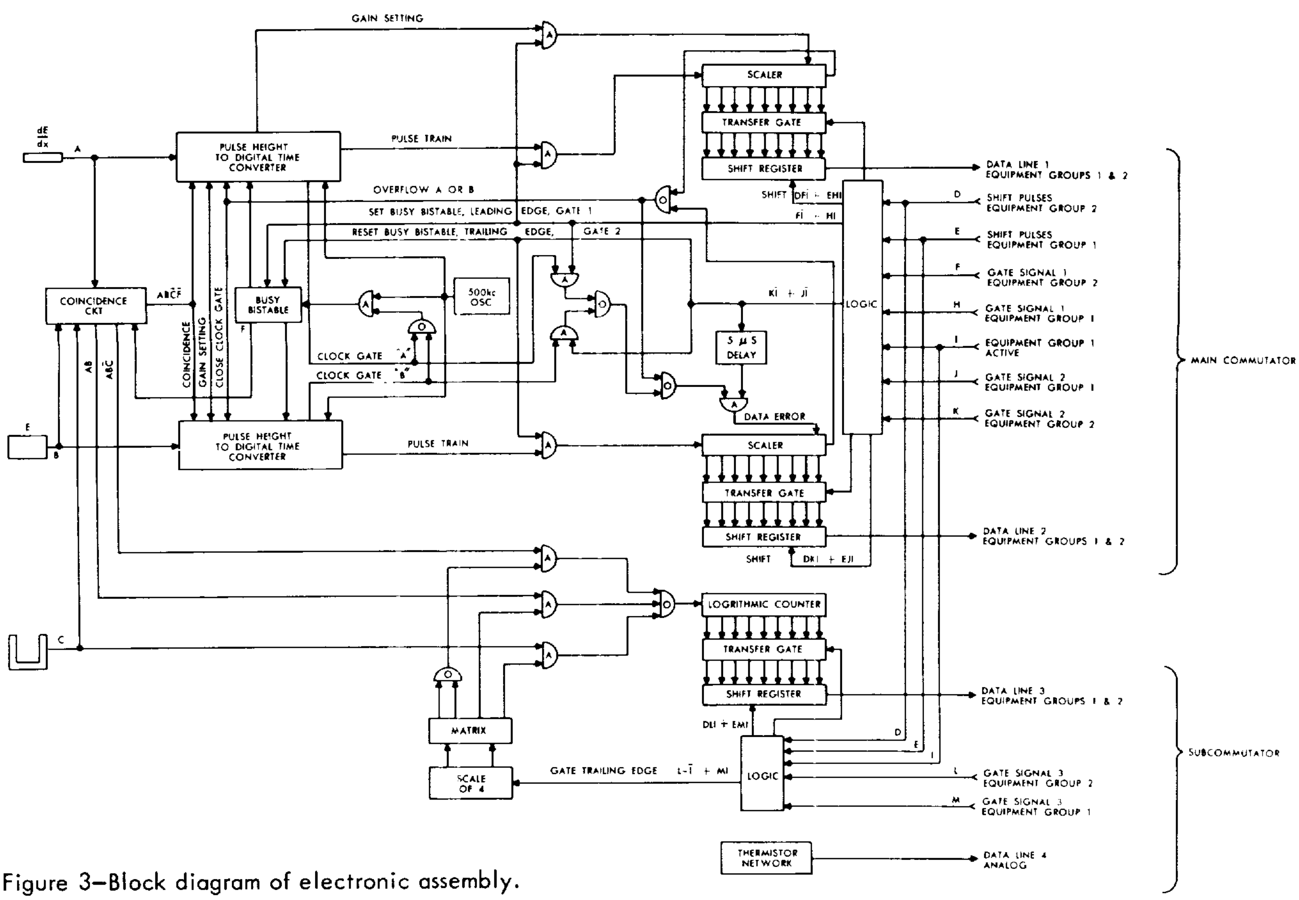


Figure 3—Block diagram of electronic assembly.

RANGE AND SENSITIVITY

In practice it is impossible to measure dE/dx without changing the energy of the particle at the same time, and instead of obtaining dE/dx and E we obtain $\Delta E/\Delta x$ and $E-\Delta E$. This distinction will be made in the text, however, only where necessary.

The calculated relations between the ΔE and $E-\Delta E$ signals are shown in Figure 4 for various particles, including the isotopes of H and He. Note that the energy range for protons and alpha particles, for example, is from 6 Mev/nucleon to 76 Mev/nucleon. Figure 5 shows the calculated relations between the light outputs of the crystals when allowance is made for the experimentally measured non-linearity between light output and energy loss in CsI (Reference 2, 3, and 4). The dashed lines show for comparison ΔE plotted against $E-\Delta E$ for protons and O.

In the satellite, both the dE/dx and E signals will be analyzed and sorted digitally into 256 channels each. To accommodate heavy particles as well as protons and alpha particles, two ranges of sensitivity are required; they are shown by the open blocks in Figure 5. The proton and alpha-particle dE/dx signals are covered by 256 channels at 0.1 Mev/channel, and their E signals, by 256 channels at 1.0 Mev/channel. The heavier particles need 0.5 Mev/channel and 10 Mev/channel for the dE/dx and E measurements respectively. The analyzers will normally operate in the proton and alpha-particle mode, and switch over to the heavy-particle mode only when a heavy particle is detected. The expected rates of the various particles are such that less than 20 percent of the heavy particles will be missed by this method, while in the proton and alpha-particle mode, the apparatus will be almost continuously sensitive to intensity modulations.

REPORT OF COSMIC RAY MEASUREMENTS MADE BY THE dE/dx AND E TECHNIQUE

A series of balloons were flown carrying apparatus very similar to that shown in Figure 2, except that the E scintillator consisted of 9 gm/cm^2 of CsI and the dE/dx scintillator consisted of

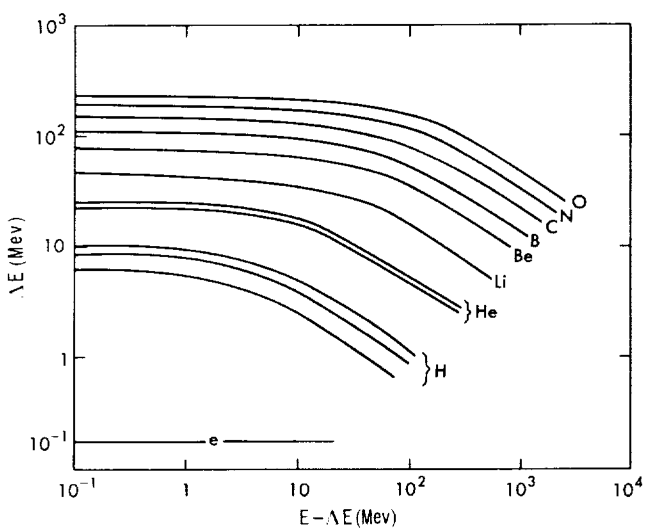


Figure 4—Energy relations for various particles.

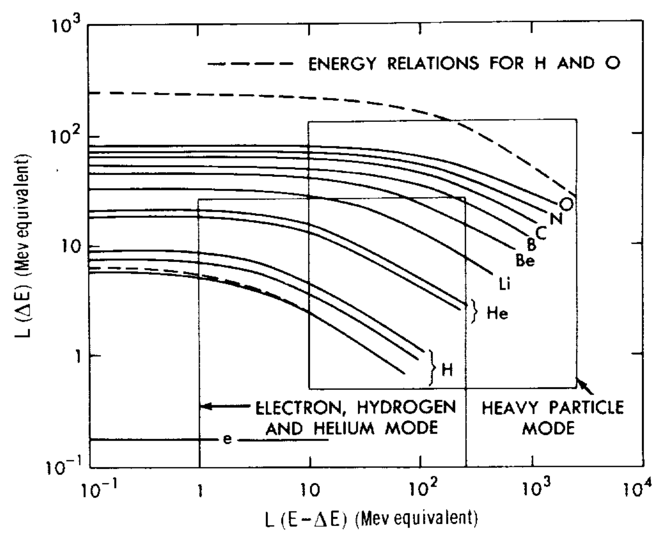


Figure 5—Light output relations for various particles.

0.4 gm/cm^2 of plastic (the latter material being readily available at the time). For this purpose, a plastic scintillator is inferior to a CsI crystal since it exhibits a marked nonlinearity between energy loss and light output (References 5 and 6). For the balloon flights, the dE/dx and E signals were each recorded on 128-channel analyzers, and standard analog-to-digital conversion cards from Nuclear Data Corporation of Madison, Wisconsin, were used. For each event, two seven-bit words representing dE/dx and E, together with anticoincidence signals from the third scintillator and timing information, were recorded on a miniature 16-channel tape recorder in the balloon gondola.

Figure 6 illustrates the resolution of the detector by showing the frequency distribution of signals from the dE/dx scintillator due to cosmic ray mu-mesons at sea level. The spread in the signal is seen to be only slightly greater than the inherent Landau spread due to statistical fluctuations in energy loss (about 15 percent for relativistic mu-mesons in a thin absorber). This shows that the spread introduced by geometrical factors and non-uniformity of light collection is of the same order or less.

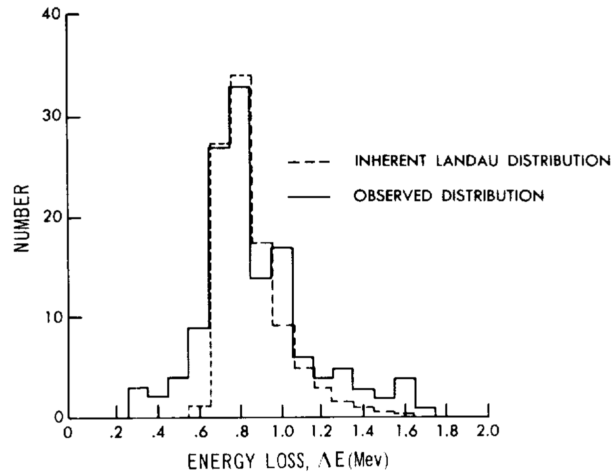


Figure 6—Frequency distribution of sea level μ-mesons in ΔE scintillator.

Figure 7 shows how the dE/dx and E measurements made at 125,000 feet (an atmospheric depth of 4 gm/cm^2) permit identification of cosmic ray particles. It should be pointed out that these results are preliminary and represent only about one third of the data from a 12-hour flight. The experimental points are superimposed on the theoretical relations for various particles in which allowance has been made for the nonlinearity of the plastic and CsI scintillators (References 2-6).

There is a very clear proton distribution lying close about the predicted curve. It has a spread of about 10 percent, as expected, from the sea-level mu-meson distribution. The spread of the electron group is larger than can be explained by statistical fluctuations alone, and is probably due to the familiar range

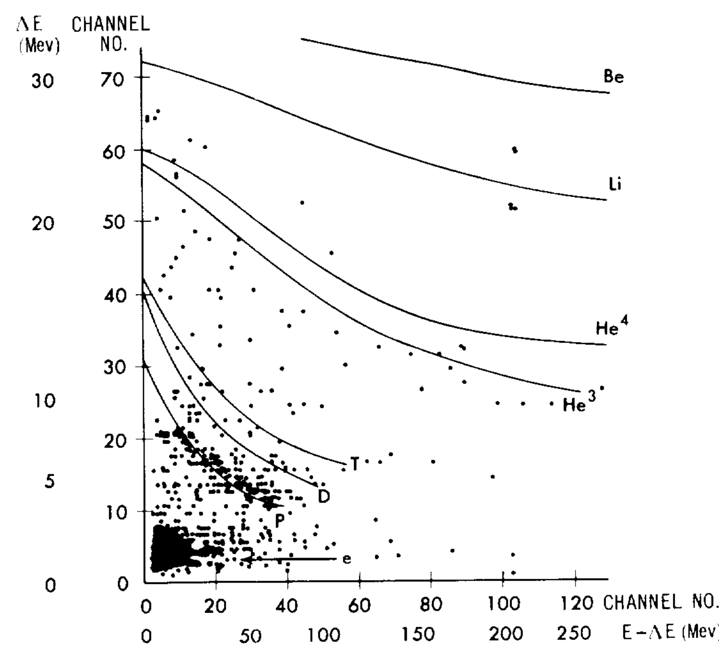
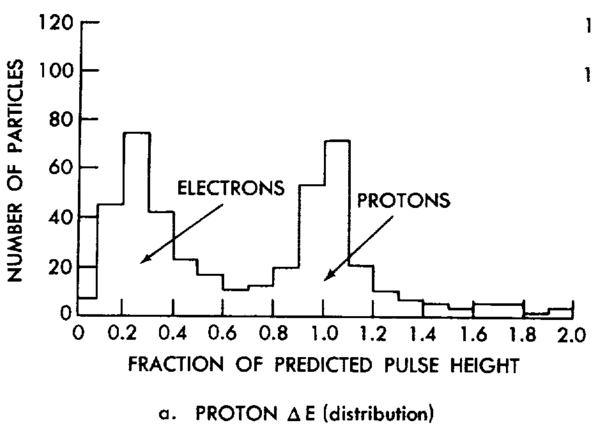


Figure 7—Measurements of ΔE and E-ΔE at 125,000 feet (4 gm/cm^2)

straggling and the results of electron showers produced in the few gm/cm^2 of atmosphere above the detector. About 40 points can be identified as He nuclei, with the separation of the He^3 and He^4 predicted curves being very close to the limit of the equipment's resolution. Thus, until the density of points is increased threefold by analysis of data from the rest of the flight, the relative numbers of He^3 and He^4 nuclei cannot be determined. The same considerations apply to deuterons and tritons. The relative numbers of He nuclei and protons are roughly 1:7, as was expected. In the present data only a few points represent particles heavier than alpha particles. The background of points may probably be accounted for by more than one particle at a time entering the dE/dx and E scintillators as a result of nuclear interactions in the atmosphere above the detector and in the detector material itself.

Figure 8 shows a cross-section, parallel to the ΔE axis, of the proton and He grouped points near the predicted curves. From the proton cross-section in Figure 8a, we see that most of the points lie within 10 percent of the predicted value. A point lying halfway between the He^3 and He^4 predicted curves would fall at 1.0 on the scale of Figure 8b; therefore, He^3 particles should fall below 1.0, and He^4 should fall above. It is thus far impossible to distinguish two humps in the distribution at this stage, but as was mentioned before, analysis of the remainder of the data should make it possible to determine the relative intensities of these two components.



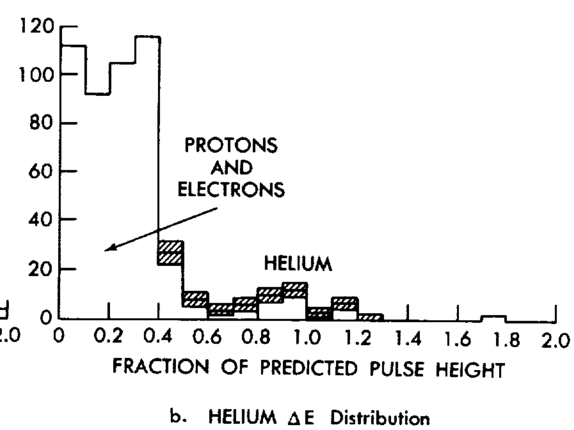


Figure 8—Cross sections of Proton and Helium ΔE distributions; the shading indicates statistical uncertainty.

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